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Seasonal forecasting of the spring growth and flowering of forage crops in the British Isles

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Introduction

During the spring months in the British Isles the growth of grass and other forage crops is often limited by climatic conditions such as low temperatures at a time when the light available for photosynthesis is quite high. Growth may also be restricted due to water-logging of the soil, and occasionally it may be affected by soil water deficit.

A further factor which may affect the spring growth is a lack of nitrogen in the soil following winter leaching. In general the nitrifying bacteria in the soil, which are affected by temperature, only become active after grass growth has started and nitrogenous fertilizer must be applied in order to make maximum use of these periods of potential growth.

If an attempt is to be made to forecast for any year the expected growth of a forage crop in spring, including the increase in harvestable dry matter, and the approximate date of heading (50% ear emergence), it is necessary to define a model for the response of the crop to a given sequence of climatic conditions. In this paper attention will be concentrated on the perennial grasses, and some results of experiments at the Grassland Research Institute at Hurley and at the Welsh Plant Breeding Station at Aberystwyth have been used to devise a simple model of the crop growth. Certain routine meteorological observations have been used to estimate the growth in recent years.

The spring growth of forage grasses

During the winter the grass crop is in a vegetative phase, but in the spring floral initiation takes place, and a reproductive phase occurs with rapid stem elongation of fertile tillers. The time of initiation depends mainly on photoperiod (Cooper 1952) and occurs in March in many early-flowering varieties but not until April or May in late flowering varieties. Heading (defined as 50% ear emergence of fertile tillers) occurs in May for cocksfoot (Dactylis glomerata) and early flowering ryegrass, but not until June for timothy (Phleum pratense) and late flowering ryegrass (Lolium perenne). Considerable differences in the heading date of a single variety may occur between different sites and in different years as the rate of floral development depends markedly on the temperature (Cooper 1952).

The usual definitions of "earliness" or "lateness" of the spring growth of different grass varieties are largely related to the relative timing of floral initiation. Visible differences can be seen in the height of the sward, and the extension of a greater proportion of the plant above cutting height (about 5 cm) leads to a more rapid increase in the yield of dry matter of

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early varieties as measured by conventional methods of sampling (Davies and Calder, 1969). However, the increase in dry matter of the total above-ground parts of the plant may be approximately the same in both early and late varieties. If March is warm enough for considerable growth to take place, then the apparent differences in the timing of spring growth of early and late varieties may be quite large, but during 1969 and 1970, such differences have been small due to the very low temperatures in March and early April.

Data from Hurley have shown that at the end of February the leaf area index of an intensively managed grass sward is usually between 1 and 2 and that about 40% of the incoming sun and sky radiation is intercepted by the crop. As the leaf area index increases to about 6 or 7, the efficiency of light interception increases to about 95%. Since light energy is not limiting during this period the increase in above-ground material is largely determined by the rate at which the leaves can expand. A fully comprehensive model of crop growth in terms of the increase in dry weight of the various parts of the plant would have to include the calculation of gross photosynthesis and respiration, and the distribution of assimilates between below and above-ground parts. This has not been attempted in the present analysis. Instead it has been assumed that there is a relationship between the increase in the leaf area index and the increase in fresh weight of the crop. To a certain extent a similar relationship will exist between the leaf area index and the dry weight. Once rapid elongation of fertile tillers is taking place, the dry weight will also include a considerable contribution from stem material.

If a grass sward is not very dense, then initially there may be an increase in the number of tillers per unit area, but otherwise the number remains relatively constant. As a first approximation it may be assumed that there is about 1 tiller per cm^2 and that on average one leaf per tiller is expanding actively (Ryle 1964). Taking a mean leaf width of 1.8 mm then the increase in leaf area index (L) per day can be written as:

$$\delta L = k(\delta l) - c \qquad (1)$$

where δl is the increase in leaf length in mm day^{-1} and c represents a constant loss of leaf material per day.

k = leaf width x no of expanding leaves per tiller x

no of tillers per unit area = 0.018 cm^{-1}

$$\text{Thus } L(t) = L(0) + k\,\Sigma\delta l - ct \qquad (2)$$

where L (0) is the leaf area index at time t = 0.

In this model the figures quoted refer to Lolium perenne, cv. perennial ryegrass, S.24, but in general can be applied to most varieties of temperate perennial ryegrass.

Relations between the rate of leaf extension and mean daily soil temperatures

Some recent work at Hurley (Peacock 1971) has shown that when soil water and nutrition are adequate, the rate of extension of the youngest leaf on a tiller of Lolium perenne perennial ryegrass cv. S.24 depends mainly on the temperature just below the soil surface. Figure 1 shows the values obtained

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during the spring period in 1970, using soil temperatures at 2 cm, meaned over the period of measurement of the leaf extension. The data have been fitted by an asymptotic curve of the form

$$\delta l = A + BC^{\bar{T}} \qquad (3)$$

$\bar{T}$ is the mean soil temperature in °C.

$A = -5.0 \pm 2.2$

$B = 4.7 \pm 1.7$

$C = 1.173 \pm 0.031$

It can be seen that some leaf extension occurs even at very low temperatures, but this may not be sufficient to compensate for the loss of plant material by decay. Above about 5°C (41°F) the rate of leaf extension increases quite rapidly with increasing temperature, but there is no marked "growth" threshold at this temperature.

It was found that the response curves were almost identical if the mean daily temperatures were measured at 2 cm, 5 cm, 10 cm or 20 cm depth. This was due to a close correlation between changes in the mean daily temperature at the different depths. In this particular soil, a sandy loam, the time lag for the diurnal temperature wave was only 3.5 hours between 2 cm and 20 cm depth, while for the annual wave it would be about 3 days. In certain soils, such as peat, these temperature lags would be much greater, and could amount to 9 days in the annual wave.

Calculation of the leaf area index using temperature measurement

Daily values of mean soil temperature under a sward of S.24 perennial ryegrass were measured at Hurley for 1968, 1969 and 1970, and leaf area indices were measured during the period of spring growth in the last two of these years. Using the relationship between leaf extension and temperature obtained in 1970, daily values of δl and $\Sigma \delta l$, the accumulated leaf extension, were calculated, starting from 1 March. There were 6 measurements of leaf area index during the period 1 March 1970 to 25 April 1970 and a multiple regression was fitted to the observed and calculated values to obtain values for the constants k and c in equation (1). The resulting regression for leaf area index was:

$$L = L_o + 0.0147\,\Sigma(\delta l) - 0.0290t \pm 0.100 \qquad (4)$$

with $k = 0.0147 \pm 0.0012$ as compared with $k = 0.018$, the value postulated for equation (1). The order of magnitude of k was as expected and the difference in values could be due to less than one leaf per tiller expanding at the calculated rate.

Equation (4) has also been applied to the data for 1969 where the initial leaf area at the beginning of March was considerably lower than in 1970. Reasonable agreement was obtained between the observed and calculated values up to 15 April, but on 22 and 29 April the observed leaf area index was considerably higher than the calculations indicated. Figure 2 shows the calculated values of leaf area index for 1969 and 1970 together with the actual observations.

Certain deduction can be made using equation (4). If the mean soil temperature is less than 2.4°C then there is a slow loss of leaf area. In Table 1 the daily increase in leaf area at different temperatures is given.

/Table 1

Table 1

Mean daily soil temperature, °C	Daily increase in leaf area index
3	0.011
4	0.030
5	0.052
6	0.077
7	0.109
8	0.147
9	0.191
10	0.241

Thus an increase in temperature from 5°C to 7°C would double the daily rate of increase of leaf area, and at 10°C it would be almost 5 times the rate at 5°C.

Dry matter yields

In order to obtain an estimate of the above-ground yield of dry matter a ragression equation was calculated for 1970 data between the leaf area index and the observed yield of dry matter sampled to ground level. This gave:

$$W = 75 + 80.4\,L \pm 24 \text{ gm m}^{-2} \quad (1 \text{ gm m}^{-2} = 10 \text{ kg hectare}^{-1}) \qquad (5)$$

During March and early April most of this material would have been below normal cutting height, and from mid-April about 300 to 350 gm m^{-2} would have to be subtracted from the total to give the dry matter yields sampled by conventional methods. However, as has been pointed out by Davies and Calder (1969), this part of the above-ground yield could be utilized to some extent by sheep which graze close to the ground.

It appears that, given the initial leaf area index of a sward of S.24 perennial ryegrass at the beginning of March, and daily values of the mean soil temperature at 2 cm or 10 cm under the sward, a reasonable estimate can be made of the changes which occur in the leaf area index up to the point where leaf production ceases and the stems of fertile tillers elongate rapidly. (This assumes that mitrogen fertilisation is adequate for maximum growth). Using the calculated values of leaf area index, an estimate can then be made of the above-ground yield of dry matter. Further growth of the crop depends mainly on the progress of reproductive development and on the incoming light energy, and usually occurs at a fairly constant rate until after the time of ear emergence.

From a forecasting point of view the main information required concerns the changes in soil temperature to be expected during the coming season. Additionally it may be possible, using observed temperatures during February and March to assess the growth that has already taken place (perhaps below normal sampling height) and to use this as a basis for forecasting crop growth during April.

Relations between microclimate measurements under a grass crop and standard meteorological observations

In general mean soil temperatures are not measured under a grass sward, and it is found that under bare soil, temperatures tend to be lower during

/cold

cold periods and higher in warm periods due to the lack of an insulating cover. In particular the 0900 GMT soil temperature under bare soil is a relatively poor indicator of the mean soil temperature at the same level under a sward. As the leaf area index increases, differences become more marked and can amount to several centigrade degrees. The once-daily observation of temperature at 30 cm under short turf appears to be much more useful, particularly in soils with a large damping depth. The diurnal variation is very much smaller than at 10 cm under bare soil.

At Hurley readings were made daily in 1970 at 0900 GMT of the maximum and minimum temperatures at 10 cm depth under turf, using a mercury-in-steel thermometer with the bulb lying horizontally at the required depth. A linear regression equation was calculated between daily values of $\frac{1}{2}$ (minimum + maximum) temperature as read at 0900 GMT and, the 0900 GMT 30 cm earth temperature under turf. The months used were March, April and May. The equation obtained was:

$$T_{mean} = -0.24 + 1.12\ T_{30} \pm 0.62^{\circ}C \qquad (6)$$

T_{mean} = mean soil temperature at 10 cm

T_{30} = 0900 GMT earth temperature at 30 cm

Changes in the diurnal range of temperature at 30 cm as the mean temperature increases, and the lag of the annual temperature wave, affect the constants obtained, and these would be rather different for soils with a smaller damping depth and larger phase differences.

These observations were made in the meteorological enclosure at Hurley, about 40 m lower than the field where leaf extension and temperature have been measured in the last two years. Although the height difference is quite small, differences in soil temperature during the springs of 1969 and 1970 have been between 1°C and 2°C, probably due to the greater exposure to wind of the higher site. As a result there is likely to be a delay of between 7 and 14 days in the date at which a given leaf area index is reached at the higher site as compared with the lower one. Similar differences in air temperatures in a Stevenson screen have not been observed, and in fact night minima are higher site.

Calculated leaf area indices 1964-1970

Figure (3) shows the values of leaf area index at 5 day intervals during March and April for the years 1964 to 1970 calculated from equation (4). The initial value on 1 March was taken as 1.5 for each year. The mean soil temperatures were obtained from daily values of the 30 cm earth temperature in the meteorological enclosure using equation (6). These data show that only in 1966 and 1967 would considerable growth have taken place during March, and the decade 1961 to 1970 has been notable for the number of years (seven) in which little grass growth would have occurred before the end of March in most of England and Wales. In 1965, the late start to active growth was compensated to some extent by a warm spell of weather in late March and April.

In order to test how accurate a mean monthly earth temperature would be as an indicator of the increase in leaf area during March, the mean monthly eath temperatures at 0900 GMT were converted into mean monthly soil temperatures at 10 cm using equation (6) and a mean value of daily leaf

/extension

extension was calculated. The resulting changes in leaf area between 1 and 31 March, using daily values and mean monthly values for δl are given in Table 2.

Table 2

	Change in leaf area using mean monthly temperatures	Change in leaf area using mean daily temperatures
1964	1.74	1.95
1965	1.56	2.08
1966	3.20	3.20
1967	3.48	3.47
1968	2.24	2.42
1969	1.29	1.35
1970	1.10	1.22

The use of the mean monthly temperature gives an underestimate of the increase in leaf area in months in which there is a large rise in temperature, such as March 1965, when the minimum value during the month was 1.0°C and the maximum 8.9°C. This is because the rate of leaf extension is a non-linear function of the mean soil temperature. However, in general the mean monthly earth temperature under grass is a useful indicator of the growth to be expected during the month, with the proviso that it is likely to underestimate the final total under certain conditions.

Forecasting the mean monthly earth temperature

From February to March there appears to be a fair degree of persistence in the 30 cm earth temperatures and a multiple regression has been calculated using the observed 30 cm earth temperature for February, and the mean monthly air temperature for March. At Hurley this was:

$$T'_{earth} = 0.21T_{earth} + 0.64T'_{air} + 0.72 \pm 0.54 \qquad (7)$$

where T refers to mean February temperatures and T' to mean March temperatures. Thus a forecast monthly mean air temperature for March can be combined with the observed February earth temperature to provide a forecast of the March mean earth temperature. Because of different site and soil effects this regression should be calculated, where possible, for the site where it is to be used.

Heading of forage grasses

The time of heading of forage grasses is of interest as an indicator of changes in the digestibility of the crop. The relationship between digestibility and the stage of reproductive development varies with species and also with varieties within a given species (Aldrich and Dent, 1967; Green, Corrall and Terry, 1971). For example the digestibility of a cocksfoot is generally lower than that of a perennial ryegrass which heads at the same time; and within the ryegrasses the digestibility at the time of heading is higher in early-flowering varieties than in the later ones.

/Heading

Heading is normally defined as the date when 50% of the fertile tillers have reached ear emergence but individual tillers may reach this point of development over a period of two or three weeks. Much of the earlier work on floral development refers to spaced plants with a different definition of heading, but in practice the dates observed are very similar in both cases.

Cooper (1952) showed that much of year to year and site to site differences in heading dates could be explained by a consideration of the air temperatures between the time of floral initiation and ear emergence. He used accumulated day degrees above 42°F (5.6°C) to represent the temperature effect and found that ear emergence of spaced plants of S.24 perennial ryegrass could be related to temperature by a regression of the form

$$Y = 30.23 - 42.4 \log_{10} \left\{ \frac{T}{100} \right\} \qquad (8)$$

where Y was a date in May, and T was the accumulated temperature above 42°F during March and April. (1 Fahrenheit day degree is equivalent to 0.555 Celsius day degree). A similar regression was obtained using accumulated day degrees for April and May to give the date of heading in June of S.23 perennial ryegrass.

These regressions have been tested with some recent data of 50% ear emergence recorded by the National Institute for Agricultural Botany at their testing stations at Seale Hayne (Devon), Trawscoed (Cardiganshire), Cambridge, and Cockle Park (Northumberland); and by the Scottish Agricultural Colleges at Ayr, Edinburgh and Aberdeen. Quite reasonable agreement was obtained between the calculated and observed dates for S.23 perennial ryegrass, but with S.24 considerable differences occurred, particularly at the more northerly centres in 1967 and 1968 where very low temperatures during May led to late heading dates.

The influence of latitude has sometimes been confused with that of climate, but the latitude in itself will mainly affect the changes in day-length. Unless floral initiation occurs before the middle of March the appropriate daylength will be attained at an earlier date at more northern latitudes, and by May such differences will be considerable. There is also some evidence that floral development is accelerated by longer daylengths (Aitken, 1966). In years which have warm springs throughout the British Isles (such as 1957 and 1961) differences between the heading dates at northern and southern sites are small, although the accumulated day degree total may be somewhat smaller in the north. The effects of altitude and exposure over a height range of 1000 ft (304 m) may be as great as the average differences at sea-level between the south-west and the north-east of the British Isles. More useful results can be gained by concentrating attention on long-term climatic data for a given site together with expected deviations from these, rather than by looking for a general south to north variation.

The range of heading dates of S.24, which may be taken as being typical of the early-heading perennial grasses, in the 9-year period from 1962 to 1970 has been about 14 days at Cambridge and Seale-Hayne and 26 days at Aberdeen, and this period does not contain any spring that would be classified as 'early' as far as heading is concerned. In 1966 and 1967 mild weather in early March was followed by some quite cold spells in late March, April and May. One result of a late start to spring growth followed by a warm or average late April and May is that the dry matter yields may be a

/fortnight

fortnight or more behind those obtained in an 'average' year throughout the growth period, but the later stages of floral development are accelerated by the high temperatures. As a result the delay in heading is considerably smaller than that in reaching a given yield and there is a corresponding loss in the yield of digestible dry matter. A forecast of the probable date of ear emergence could, therefore, be of practical interest.

Following on from the results obtained with respect to leaf extension, it would appear that during the early stages of floral development, after initiation has taken place, the important temperature would not be that of the air at screen level but that of the soil just below the surface. Similarly the form of response to temperature is likely to be an asymptotic one. Once rapid elongation is taking place and the developing inflorescence is carried up to near the top of the crop, then air temperatures may provide a reasonable estimate of the temperatures may provide a reasonable estimate of the temperature affecting the inflorescence. The importance of soil temperature during the early stages may explain why the total of accumulated day degrees up to heading date tends to be lower near the west coast than it is in the east. In the former areas as compared with the latter, mean soil temperatures are generally higher during March, but mean air temperatures tend to be lower during April and May.

In assessing the effect of temperature on the date of ear emergence and hence devising some scheme of forecasting, a single agronomic observation is being compared with a sequence of climatic conditions which may be of varying importance at different stages in the development of the inflorescence. Additionally the weather during the preceding winter and the management of the sward may affect the emergence date. A calculation of accumulated day degrees above 42°F will give an indication at the end of March as to whether the heading dates of early varieties may be earlier or later than average, but probably the value of Σ (δ1), which uses an asymptotic relationship with mean soil temperatures, would be a better predictor at this stage. It may be useful to estimate the date at which $\Sigma(\delta 1)$ reaches a value of about 350 (corresponding to a leaf area index of around 5.5), but it must be remembered that changes in air temperature at crop level after this time could have a significant effect on the time of heading.

Forecasting requirements for estimating the spring growth and date of heading of perennial grasses

1. Mean soil temperature during March under a grass sward, probably from a forecast of the mean earth temperature at 30 cm depth under short turf. If the month is expected to be very cold at the start then some estimate is required of when the temperature is expected to rise substantially (if at all).

2. Mean air temperature during April; also mean soil temperature during April if March temperatures are expected to be cold at the site in question, and if the grass concerned is of a late-flowering variety.

3. Mean air temperature during May.

Considerable information on the progress so far during a given season could also be calculated from actual observations of temperature and by the end of March it should be possible to make some estimate of whether the heading of early varieties is likely to be early or late.

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Of other major forage crops in the British Isles clover tends to require slightly higher temperatures than do the temperate grasses for rapid growth to occur. Maize does not germinate at temperatures below about 15°C (59°F) and it requires high temperatures for optimum growth rates.

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Any comments or criticism on this paper should be referred to the Authors.

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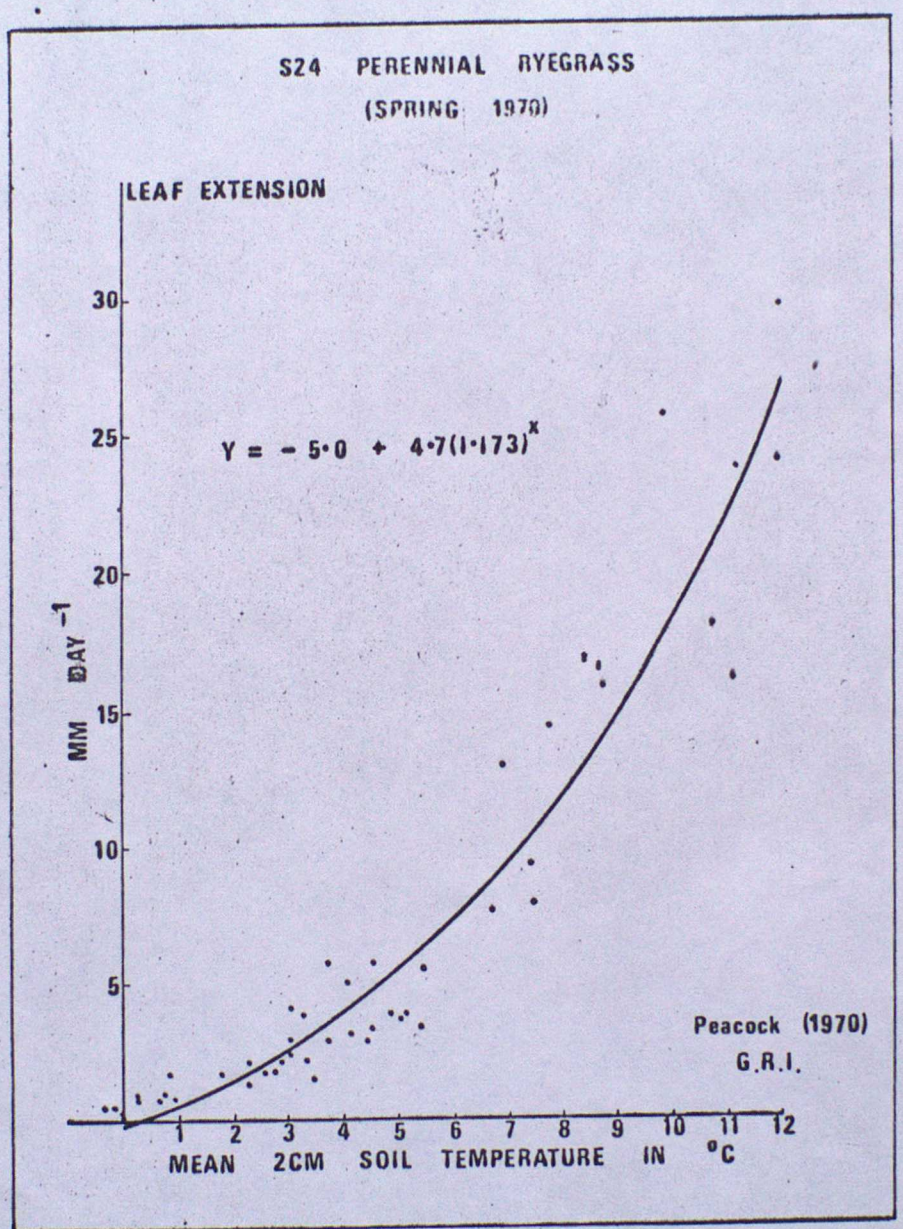
S24 PERENNIAL RYEGRASS
(SPRING 1970)
LEAF EXTENSION
Y = - 5·0 + 4·7(1·173)^X
MM DAY -1
30
25
20
15
10
5
1 2 3 4 5 6 7 8 9 10 11 12
MEAN 2CM SOIL TEMPERATURE IN °C
Peacock (1970)
G.R.I.

FIGURE [g] 1

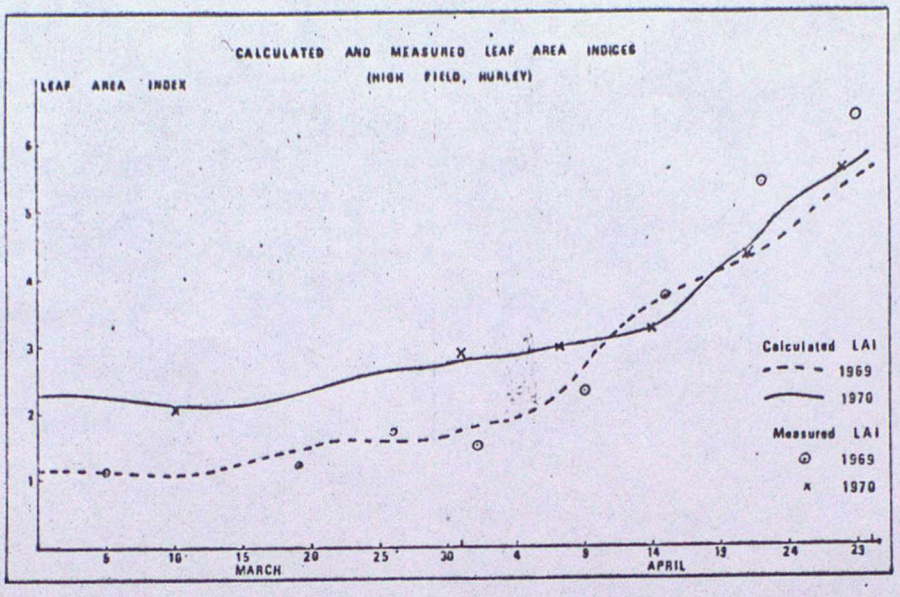

FIGURE [g] 2

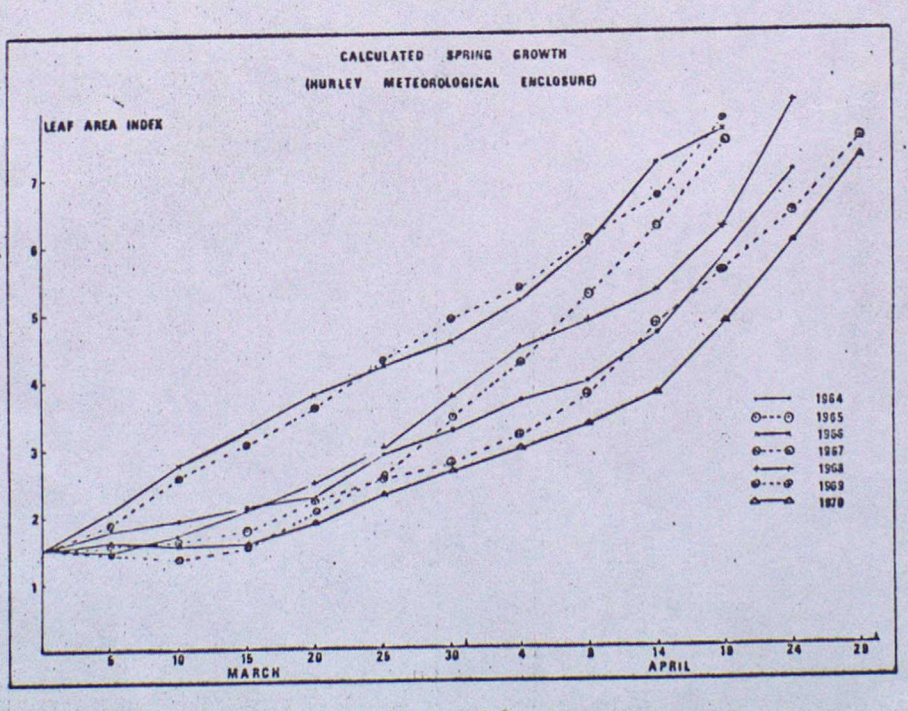

FIGURE [g] 3